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(71) Applicant: MOTOROLA INC. [US/US]; 1303 East Algonquin Road, Schaumburg, IL 60196 (US).

(72) Inventors: GHOSH, Amitava; 289 Hunter Court, Vernon Hills, IL 60061 (US). CLASSON, Brian, K.; 124 Red Cedar Drive, Streamwood, IL 60107 (US). CUDAK, Mark, C.; 3318 Chestnut Drive, McHenry, IL 60050 (US). JALLOUL, Louay; 1501 Churchill Drive, #104, Palatine, IL 60067 (US).

(74) Agents: WILLIAMS, Lalita, P. et al.; Motorola Inc., Intellectual Property Dept., 1303 East Algonquin Road, Schaumburg, IL 60196 (US).

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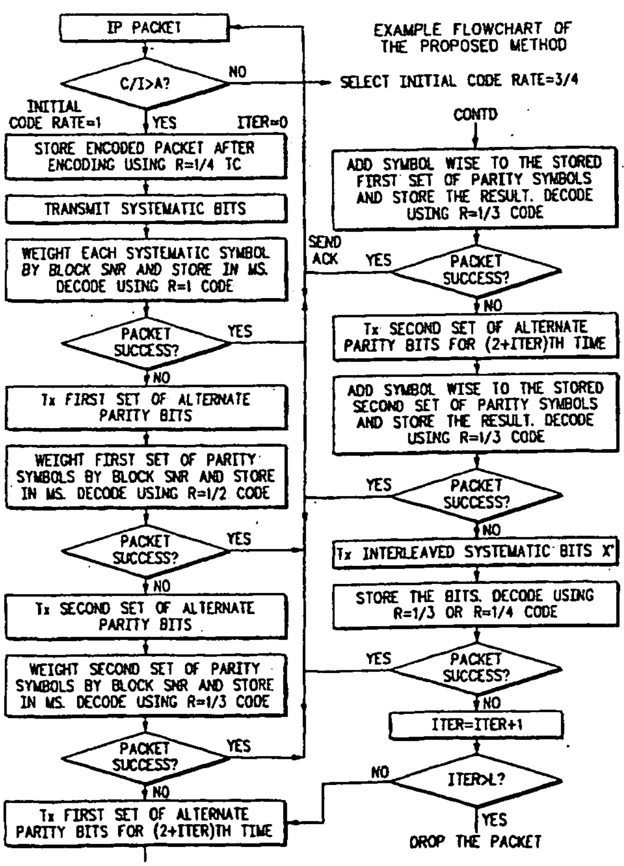
(54) Title: ADAPTIVE HYBRID ARQ USING TURBO CODE STRUCTURE



(57) Abstract: A generic structure of Hybrid ARQ using Turbo Codes is provided which requires the function of channel coding, redundancy selection, buffering and maximum-ratio diversity combining, channel decoding, error detection, and sending back an acknowledgement to the transmitter (Fig.3). The functions of channel coding and redundancy selection (Fig.1) are performed at the transmitter while the remaining functions are performed at the receiver. The initial code rate can be explicitly communicated to the receiver or blindly detected.

WO 01/37433 A1

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H03M 13/29, 13/35; H04L 1/02
US CL :714/751, 774, 790
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 714/751, 774, 790

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PTO EAST: turbo <and> ARQ
IEEE Online: turbo <and> ARQ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	ROWITCH et al., "Rate Compatible Punctured Turbo (RCPT) Codes in a Hybrid FEC/ARQ System", ICC '97, pages 55-59, especially sections 2.2 and 2.3, and figures 2 and 3.	6, 7, 9, 10 — 8
Y	US 5,978,365 A (YI) 02 November 1999, col. 4, lines 7-16, Figures 3, 6, 9.	8
A	US, 5,983,384 A (ROSS) 09 November 1999, see abstract.	1, 6

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	STEPHEN M. BAKER
Facsimile No. (703) 305-3230	Telephone No. (703) 305-3800

Adaptive Hybrid ARQ Using Turbo Code Structure

Field of the Invention

The present invention relates generally to communication systems and in particular, to adaptive hybrid ARQ using turbo code structure.

Background of the Invention

Adaptive Modulation and Coding (AMC) gives the flexibility to match the modulation and forward error correction (FEC) coding scheme to the average channel conditions for each user. AMC promises a large increase in average data rate for users that have a favorable channel quality due to their proximity to the base site or other geographical advantage. Enhanced GSM systems using AMC offer data rates as high as 384 kbps compared 100 kbps without AMC. Likewise, 1.25 MHz CDMA systems can offer peak data rates as high as 5 Mbps through AMC, where 460 kbps was typical without AMC. AMC, however, does have a few drawbacks. AMC is sensitive to measurement error and delay. In order to select the appropriate modulation, the scheduler must be aware of the channel quality. Errors in the channel estimate will cause the scheduler to select the wrong data rate and either transmits at too high a power, wasting system capacity, or too low a power, raising the block error rate. Delay in reporting channel measurements also reduces the reliability of the channel quality estimate due to constantly varying mobile channel.

To overcome measurement delay, the frequency of the channel measurement reports may be increased, however, the measurement reports consume system capacity that otherwise might be used to carry data.

For these reasons, AMC is often used to provide a coarse data rate selection, perhaps based on a sub-optimum channel estimate as compared to a set of independent thresholds. Automatic Repeat request (ARQ) can be used in conjunction with AMC to ensure data delivery by requesting retransmissions of erroneously received blocks. The retransmission request can be ACK or NACK based. AMC is improved with ARQ because it can automatically adapt to *instantaneous* channel conditions. The combined AMC (or FEC) and ARQ design process is very complex, involving FEC performance in

the channel of interest as well as delay and implementation complexity constraints. Using FEC+ARQ together is known as a *type I hybrid ARQ*.

Even greater throughputs or error performance can be achieved with *type II hybrid ARQ*. This scheme, designated *Hybrid ARQ* in the remainder, is similar to standard ARQ in that it repeats all blocks that have been received in error. However, Hybrid ARQ improves on standard ARQ methods by saving and using failed transmission blocks at the receiver to increase the coding gain. The failed transmission blocks are jointly decoded with the current block in order to improve performance. The blocks that are sent by the transmitter are considered part of a larger code. Because additional parts of this code are sent only in response to the instantaneous channel conditions, Hybrid ARQ is also correctly known as *Incremental Redundancy* or *Adaptive Hybrid ARQ*.

There are several different flavors of Hybrid ARQ. The simplest flavor is code combining (also known as Chase combining), which simply repeats the first block for each transmission. The joint decoder is a block repetition decoder can be implemented as a block combiner, which can look like an equal gain combiner or max-ratio combiner, followed by a single block decoder. Because code combining is in effect a repetition coding scheme, it is correctly classified as a type II hybrid ARQ. Advantages of Chase combining compared to other Hybrid ARQ methods include smaller decoder complexity, smaller memory requirements, the ability to self-decode every block before joint decoding, and not having to specify maximum number of transmission attempts.

However, Hybrid ARQ methods that provide more sophisticated coding methods over the blocks than the simple block repetition code may offer larger coding gains. Hybrid ARQ schemes can be designed such that the first L blocks form part of a larger code. Construction techniques are available for many types of codes, including Reed-Solomon codes, convolutional codes, and turbo codes. The L code blocks may also be partially overlapping, with some symbol positions repeated in more than one block. These positions can be treated with a symbol combiner, similar to the block combiner. After L transmissions, the blocks are repeated, with the old blocks either combined with or replaced by the new blocks.

A self-decodable block is one that may be decoded by itself before joint decoding. Obviously, the first of the L blocks is always self-decodable. If the first block is severely damaged in transmission, it is advantageous to have the other blocks self-decodable as well. The term type III hybrid ARQ was used in S. Kallel, "Complementary punctured convolutional codes and their applications," IEEE Trans. Commun., June 1995, to refer to the class of Hybrid ARQ protocols in which all blocks are self-decodable.

Since, as stated in Siemens AG *TSGR1#3(99)177*, March 22-26 1999 types II and III are "minor variants of the same scheme", no special designation is required. However, the use of the designation emphasizes the fact that either only the first block or all L blocks are self-decodable, and that the self-decodable schemes require special care to construct .

Hybrid ARQ improvements can greatly increase user throughputs, potentially doubling system capacity. In effect, Hybrid ARQ adapts to the channel by sending additional increments of redundancy, which increases the coding rate and effectively lowers the data rate to match the channel. Hybrid ARQ does not rely only on channel estimates but also relies on the errors signaled by the ARQ protocol. Hybrid ARQ is even more difficult to design than FEC+ARQ, because of additional control, code construction, and decoder implementation issues. In addition, Hybrid ARQ also complicate the ARQ protocol implementation.

Turbo codes, which provide error correction gains close to the theoretical Shannon limit, can be used in conjunction with hybrid ARQ. Several prior art approaches exist, including code combining, punctured turbo codes and *a priori* methods. These methods, however, do not make the best possible use of the turbo code structure in fading channels. These methods do also not handle combining adaptive coding and modulation with hybrid ARQ.

Prior-art ARQs do not make the best use of the turbo code structure in fading channels. Additionally, retransmissions are the same size as the original transmission and the throughput cost for a second transmission is significant. Prior-art ARQs not have provisions for self-decodable blocks other than the first block, without having all the blocks self-decodable and the self-decodable blocks must be at least the same size as the information packet.

Thus, there is a need for a turbo hybrid ARQ that does not suffer from these limitations of the prior art. The invention provides a turbo hybrid ARQ that contains self-decodable blocks other than the first block, allows retransmissions of different sizes, and is better on fading channels.

Brief Description of the Drawings

FIG. 1 is a block diagram of a turbo encoder in accordance with the preferred embodiment of the present invention.

FIG. 2 is a flow chart showing adaptive hybrid ARQ in accordance with the preferred embodiment of the present invention.

FIG. 3 is a flow chart showing adaptive hybrid ARQ in accordance with the preferred embodiment of the present invention.

FIG. 4 an example of the transmission blocks used in the scheme along with the block transmission sequence for various selected initial turbo code rate.

Detailed Description of the Drawings

The Turbo codes used in the proposed hybrid ARQ system consists of a parallel concatenation of two convolutional encoders as shown in FIG. 1. In a preferred embodiment, the encoders are identical R=1/2 systematic and recursive convolutional encoders. The overall code rate of the turbo code entering the puncturing circuit for the preferred embodiment is ¼. For an input stream, four output streams are formed: the input stream x itself, a parity stream produced by the first convolutional code y_1, interleaved input stream x' and the second parity stream y_2 produced by the second convolutional code. The puncturing block after the encoder is used to form (for example) R=3/4, R=2/3 and R=1/2 codes by puncturing the parity bits. As an example, for R=1/2 codes alternate parity bits are sent over the channel (x_1, y_{11}, x_2, y_{21}, x_3, y_{12},....x_N, y_{1N} where N is the size of Turbo interleaver) In case of R=1/3 code the interleaved systematic bits (x') are not sent over the channel.

The proposed method is described below with the flowchart shown in FIG.s 2 and 3. FIG. 2, shows the generic structure of Hybrid ARQ using Turbo Codes which requires the function of a) channel coding, b) redundancy selection, c) buffering and max-ratio diversity combining, d) channel decoding, e) error detection and f) sending back an acknowledgement to the transmitter. As illustrated in FIG. 2, the functions (a) and (b) are performed at the transmitter while functions (c) to (f) are performed at the receiver. The initial code rate can be explicitly communicated to the receiver or blindly detected. FIG. 4 shows an example of the transmission blocks used in the scheme along with the block transmission sequence for various selected initial turbo code rate.

Finally, FIG. 3 shows a specific example of the proposed scheme with initial code rate chosen as 1.

1. The initial coding rate for hybrid ARQ is first chosen. The rate can be detected at the receiver using blind rate detection or explicit rate detection.
   - If C/I > A initial Turbo code rate = 1 where A is some preset threshold
   - Otherwise initial Turbo code rate = ¾ (or ½ if below another threshold B)

2. Assuming the initial code rate = 1, the following steps are performed
3. Encode entire packet using rate $R=1/4$ Turbo Code
4. Transmit systematic bits only
5. Decode systematic bits ($X_1, X_2, \ldots, X_N$) using hard decision
   - ξ if Packet Success, then done (send ACK)
   - ξ else weight each channel symbol by block SNR and store
6. Transmit the first set of alternating parity bits ($Y_{11}, Y_{22}, \ldots, Y_{2N}$)
7. Decode using R=1/2 Turbo Code
   - ξ if Packet Success, then done (send ACK)
   - ξ else weight each channel symbol by block SNR and store
8. Transmit the second set of alternating parity bits ($Y_{12}, Y_{21}, \ldots, Y_{2N}$)
9. Decode using R=1/3 code
   - ξ if Packet Success, then done (send ACK)
   - ξ else weight each channel symbol by block SNR and store
10. Transmit the first set of alternating parity bits for the second time ($Y_{11}, Y_{22}, \ldots, Y_{2N}$)
11. Add symbol-wise to the stored first set of alternating parity bits
    - decode the result using a rate 1/3 code
    - if Packet Success, then done (send ACK)
    - else store the weighted combined block
12. Transmit the second set of alternating parity bits for the second time ($Y_{12}, Y_{21}, \ldots, Y_{2N}$)
13. Add symbol-wise to the second set of alternating parity bits
    - decode the result using a rate 1/3 code
    - if Packet Success, then done (send ACK)
    - else store the weighted combined block
14. Transmit interleaved systematic bits (**x'**)
15. Decode the result using R=1/4 code
    - if Packet Success, then done (send ACK)
    - else store the weighted block
16. Transmit the first set of alternating parity bits for the third time and so on
17. Iterate steps 9 to 16 X times.
    - ξ If Packet Success send ACK
    - ξ Otherwise drop the packet

It may be noted that at step (15) one could either use weighted systematic bits combined with the previous block of systematic bits and decode it as a R=1/3 code or can

use the interleaved systematic bits and decode it as a R=1/4 code. The exact decoding method can be predetermined or communicated to the receiver during call set up or using in-band signaling.

We claim

1. A method for transmitting data packets, the method comprising the steps of:

receiving an incoming data packet;

determining an initial turbo code rate based on a channel condition;

turbo encoding the data packet to produce encoded bits comprising a plurality of systematic bits and a plurality of parity bits;

transmitting a first portion of the encoded bits based on the initial turbo code rate;

determining if an acknowledgment has been received for the transmitted first portion; and

based on the acknowledgment and the initial turbo code rate, transmitting a second portion of the encoded bits.

2. The method of claim 1 where the second portion of encoded bits is smaller than the first portion of encoded bits.

3. The method of claim 1 where the a plurality of systematic and a plurality of parity bits are stored.

4. The method of claim 1 where the channel condition used to determine the initial turbo code rate is a carrier-to-interference ratio.

5. The method of claim 1 where the channel conditions used to determine the initial turbo code rate are determined by the transmitter.

6. A method for receiving data packets, the method comprising the steps of:

receiving a portion of the encoded data packet;

determining the content of information and parity symbols in the received portion based on the initial code rate for the first received portion;

combining the portion of the encoded data packet with the previous combined portion of the same encoded data packet;

storing the combined portion;

joint turbo decoding the combined portion to produce decoded bits;

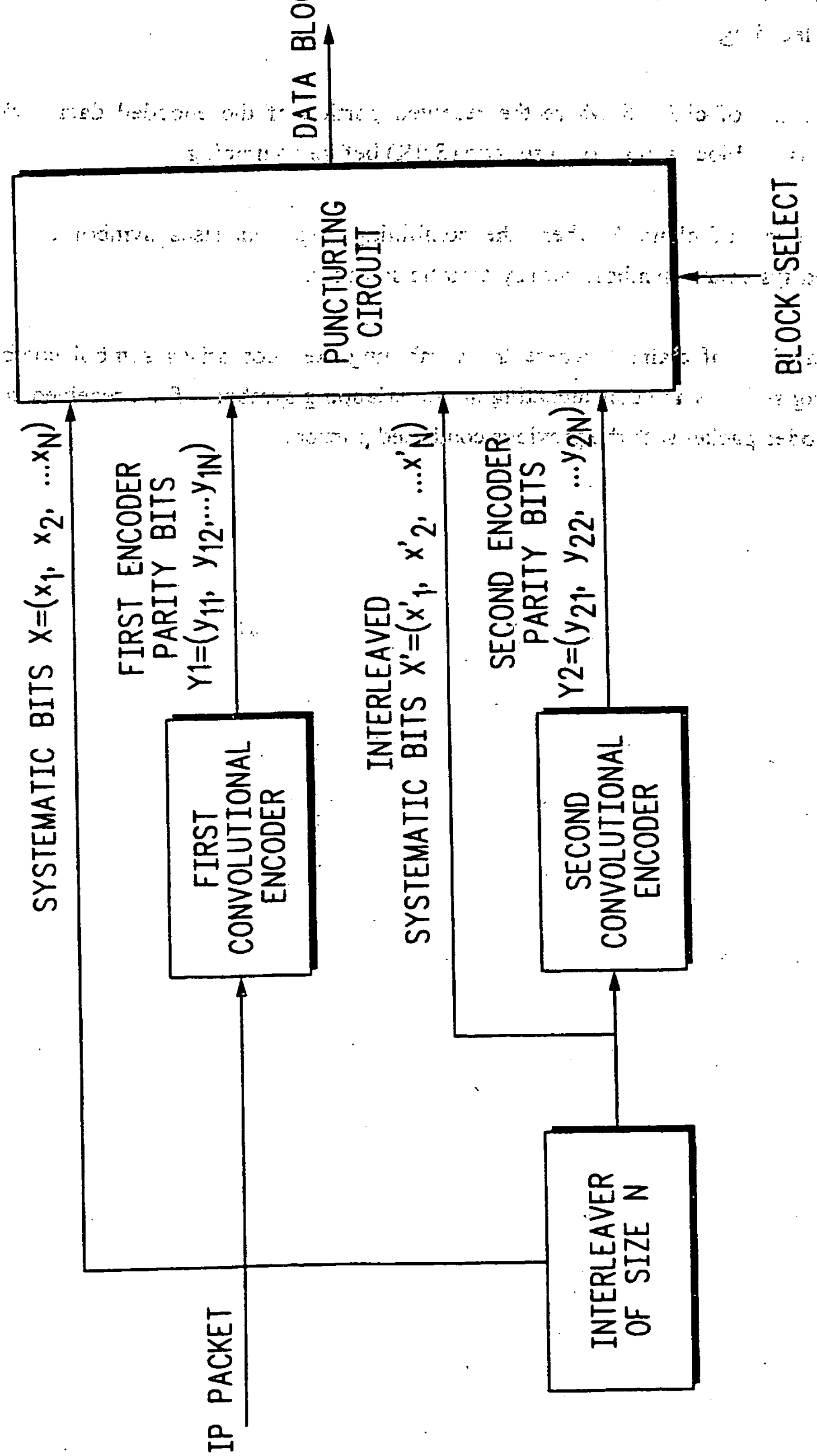
acknowledging if no error is present in the decoded bits.

7. The method of claim 6 where an attempt is made to separately decode the self-decodable received portion of the encoded data packet before, if unsuccessful, combining and joint decoding.

8. The method of claim 6 where the received portion of the encoded data packet is weighted with a block signal to noise ratio (SNR) before combining.

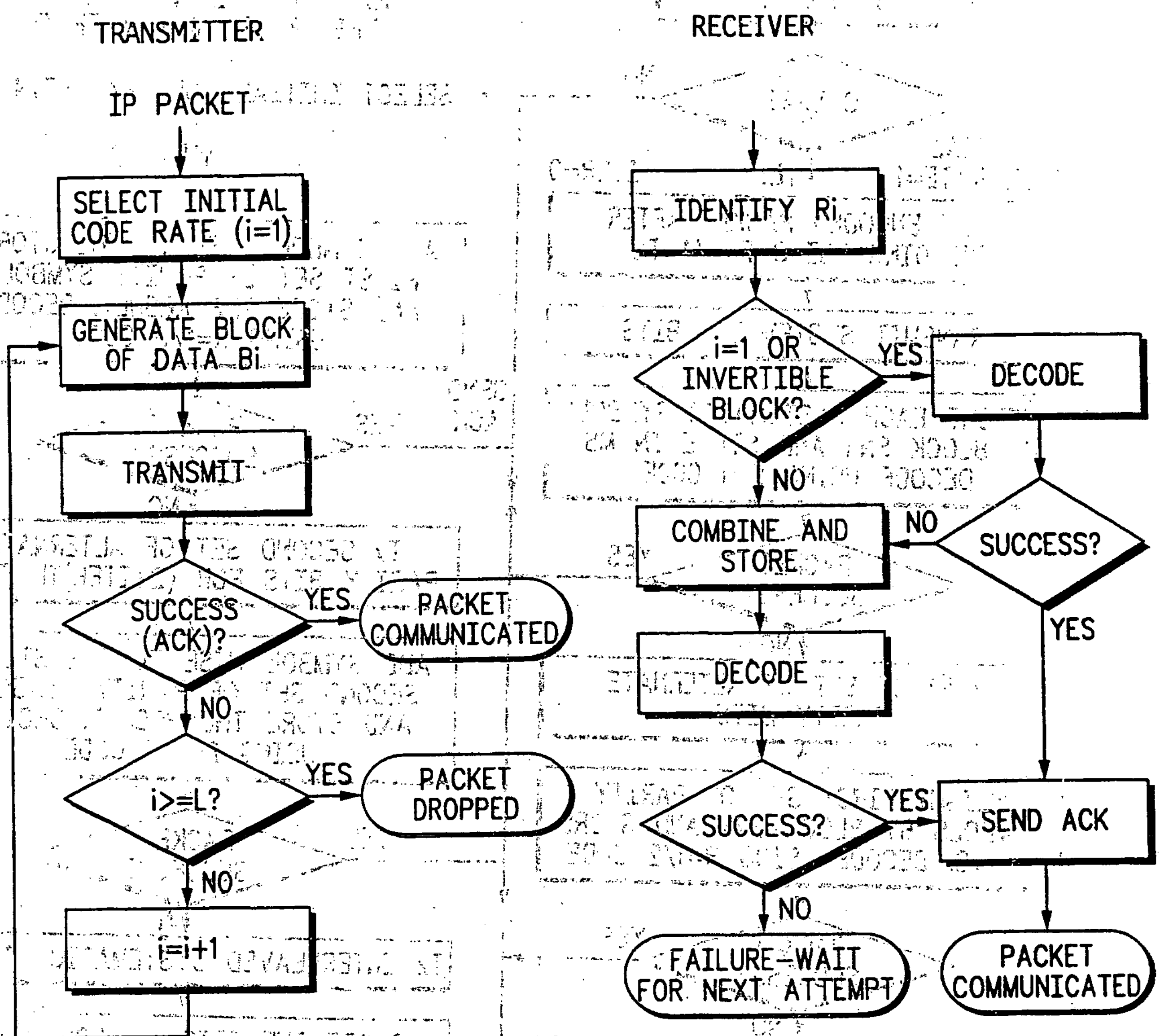
9. The method of claim 6 where the combining step comprises symbol combining interleaved systematic symbols with systematic symbols.

10. The method of claim 6 where the combining step comprises symbol combining overlapping symbols and concatenating non-overlapping symbols of the received portion of the encoded packet with the previous combined portion.



BLOCK DIAGRAM OF A TURBO ENCODER USING TWO R=1/2 CONSTITUENT CODES

FIG.1

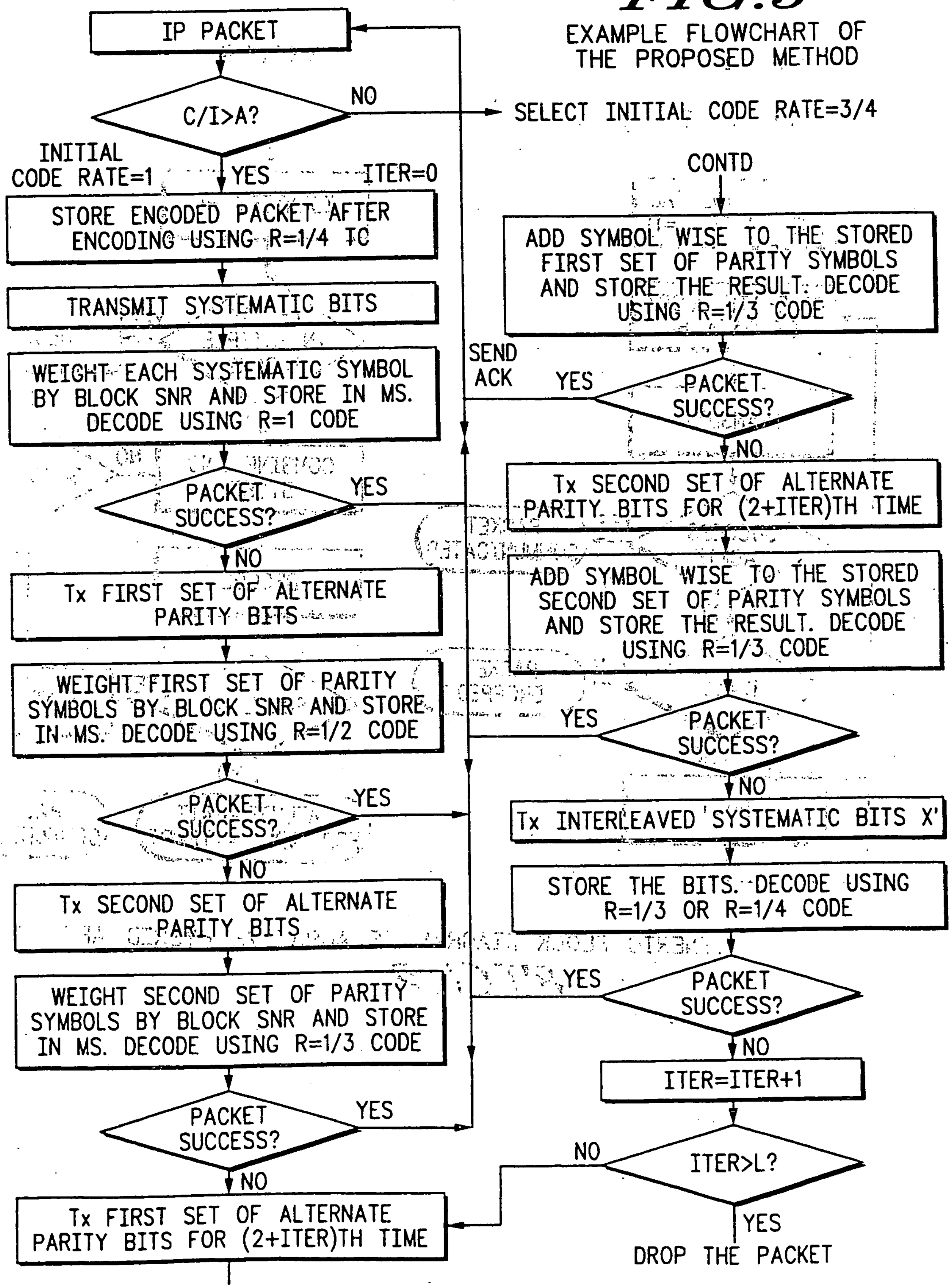


GENERIC BLOCK DIAGRAM OF ADPATIVE HYBRID ARQ

FIG.2

FIG.3

EXAMPLE FLOWCHART OF THE PROPOSED METHOD



INITIAL RATE	TRANSMISSION BLOCKS	TRANSMISSION SEQUENCE	EFFECTIVE DECODER RATE AFTER EACH TRANSMISSION
1	B_1=X B_2=1/2 OF Y_1 AND 1/2 OF Y_2 (Y_{11},Y_{22},...) B_3=OTHER 1/2 OF Y_1 AND OTHER 1/2 OF Y_2 (Y_{12},Y_{22},...) B_4=X'	B_1,B_2,B_3,B_4,B_2,B_3,B_1...	1,1/2,1/3,1/4,1/4,1/4...
1	B_1=X B_2=1/2 OF Y_1 AND 1/2 OF Y_2 (Y_{11},Y_{22},...) B_3=OTHER 1/2 OF Y_1 AND OTHER 1/2 OF Y_2 (Y_{12},Y_{22},...) B_4=X'	B_1,B_2,B_3,B_4,B_1,B_2...	1,1/2,1/3,1/4,1/4,1/4...
1/2	B_1=X+1/2 OF Y_1 AND 1/2 OF Y_2 (X_1,Y_{11},Y_{22},...) B_2=X'+OTHER 1/2 OF Y_1 AND OTHER 1/2 OF Y_2 (X'_1,Y_{12},Y_{21},...)	B_1,B_2,B_1,B_2,B_1,B_2...	1/2,1/4,1/4,1/4...
1/3	B_1=X+Y_1+Y_2 (X_1,Y_{11},Y_{21},...) B_2=X'+Y_1+Y_2 (X_1,Y_{12},Y_{22},...)	B_1,B_2,B_1,B_2,B_1,B_2...	1/3,1/4,1/4,1/4...
3/4	B_1=X+1/6 OF Y_1 AND 1/6 OF Y_2 (X_1,Y_{11},Y_{21},X_2,Y_{16},Y_{26}...) B_2=4/6 OF Y_1 AND 4/6 OF Y_2 (Y_{12},Y_{22},Y_{13},Y_{23},Y_{14},Y_{24},Y_{15},Y_{25}...) B_3=X'+1/6 OF Y_1 AND 1/6 OF Y_2 (X'_1,Y_{17},Y_{27},X'_2,Y_{113},Y_{213}...)	B_1,B_2,B_3,B_1,B_2,B_3...	3/4,3/4,3/4,1/4,1/4...

FIG. 4